Question of sulfide ore mine water form an environmental viewpoint

by P. H. Fahlstrom

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**The Question of Sulfide Ore Mine Water from an Environmental Viewpoint**

By

**Chief Engineer P. H. Fahlstrom**

Holden A/B, Mines Management Dept.

**Unedited Translation**

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Information seulement
Mining is one of the industrial activities, where environmental problems have required, and have received, a great deal of attention, because in each case it causes a consideration of the physical environment, to a larger or smaller extent. Among other aspects, mining activity depends on access to mining site, industrial district, roads, power, community facilities with recreation areas. Further, space is required for storage of byproducts. Last but not least, access to water is important for treatment of extracted ore; for recipients of used treatment water; for drained surface water and for the mine water.

Before enactment of the law for protection of the environment, there was a regulation that for construction and operation of treatment plants, an application was required to be submitted to the Water Court. The new environment protection law aims farther, and considers the mining and treatment of ore to be an industrial activity requiring concessions for implementation. Right now, as well as earlier, in the opinion of many, from an environmental viewpoint this water question is the most important one within the mining industry. In all probability it will remain so. In my opinion this is one of the reasons why the mining industry water question is discussed at to-day's meeting at Umea. Of course, to this must be added the local importance of sulfide ore mining.

Our country's sulfide ore mines are predominantly located in both most northerly counties. Most of the domestic supply of base metals of copper, lead, zinc, gold and silver and non-metallic mineral sulphur is obtained from mines in Nord- and Vasterbotten. Sulfide ore mines are young. In Vasterbotten they started with Boliden Mines, by the end of the 1920's. In Nordbotten, mining was taken up in Laisvall, 1943. Sweden's largest sulfide ore mine Aitik (beyond Gallivare) was started in 1968. Mining is
to-day one of the most important trades in Nord- and Västerbotten. The sulfide ore mines and associated activities alone employ approximately 2,350 persons. In 1970, approximately 5.5 millions of (metric) tons of sulfide ore was mined from approximately fifteen mines in these counties. Aitik and Laisvall represented 60% of the ore production.

Ore is a concentration of a mineral which can be extracted gainfully. The value of the extracted metal and general usefulness of the find must exceed the value of the resources input. In sulfide ores, the valuable minerals consist usually of sulfides of copper, lead, zinc and iron. Smaller amounts of gold and silver can occur. Minerals occur either alone in simple ores or in a mix, complex ores. Both types are common in Nord- and Västerbotten. Sulfide minerals occur in various rocks and the content is greatly varied. For instance, Aitik's copper ore contains only approximately 1.5 weight % copper mineral or 0.5% Cu while complex ore from Langsele Mine near Boliden contains over 60% sulfide minerals, amongst them copperpyrite, zincblende and sulphur pyrite.

Sulfide ore mines are of two kinds: surface mines and underground mines. The first is mined from an open pit, after the site has been stripped. Underground mines use shafts. Surface mining is used when the ore is accessible from the surface. Underground mining occurs at depths of 800 meters and more. This is the governing technique for most sulfide ore mines.

Fig. 1 Schematic illustration of a surface mine
After extraction, the ore will be taken for treatment. This is done normally in the central treatment plant which serves a number of smaller finds, or in a local treatment plant near a mine of adequate size. During treatment various ore minerals will be separated from each other, e.g. from copper, lead, zinc and sulphur-pyrite. Also, the unusable rock residue, which is part of, or comes with the ore, is separated during the process. The end products of the mine are metal sulphide concentrates and sulfur pyrite, which go for melting or other process and some unsuitable material. This is in a fine-grained form, so-called treatment sand, stirred up in the water used for the treatment process.

Mine Water

When a mine is established, it will get characteristics of a mountain well. Surface and ground water from the area are drained into it, exerting pressure in the space of the mine. The addition consists partly of surface water, partly of the water in the bedrock itself. Amount of surface water depends on precipitation and season, while the flow of ground water varies from location to location. In the deeper underground mines in Västerbotten the yearly flow varies approximately between 100,000 and 500,000 m³. In Laisvall Mine, which is located under the bottom of Lake Laisan, the bedrock is strongly water saturated, and 12 mill. m³ of water is pumped out yearly. In the surface mines the amount of mine water is limited to surface water seepage within the mine. By protective dikes, the inflow is limited as much as possible. The steady pressure of water is an inconvenience for work, and it must therefore continually be pumped out.

During its flow in the mine, the water picks up other particles. A certain amount of fine-grained material results from the mining work, and some of this is flushed out together with the mine water. This is collected
and led to settlement pools, arranged at various working levels in the mine. Pools function also as reservoirs for the pumping stations.

However, water in the mine affects even the chemical ores and rocks. In the presence of acids and carbon dioxide, water affects the base minerals. Resistance to this effect is different for various minerals. Besides, it depends also on the surface characteristics of the mineral. Under suitable conditions, the sulfide minerals, which consist of association of metals and sulphur of mine water, are affected. Herewith the sulphur atoms are oxidized into sulphate ions while corresponding metal dissolves. In a certain situation, the degree of dissolution is dependant mostly on the water's pH-value and acid contents. The lower the pH-value, the stronger the chemical reaction. The pH-value itself is in its turn a function of chemical activity of the entire system: ore-rock-water-air-temperature. Pure mineral, containing iron sulfide and which is in balance with the acid in the water, gives a solution with a pH-value of 2-3 while a number of other sulfides do not react so strongly. Presence of any small quantities of an alkaline substance, e.g. limestone, neutralizes the forming acid. Thus, the pH-value remains at a neutral level and the reaction between water and sulfide mineral will be low.

However, the pH-value affects the mine water content of metal ions in still another way. In solution, the ions of heavy metals are in equilibrium with OH-ions in the water. As a consequence, the content of metal ions decreases with higher pH-value, or alkalization. At the point of neutralization, the solubility and concentration is low for the most common ions - iron, copper, zinc, lead. At a pH-value between 9 and 10, the heavy metal ions are rejected as not easily soluble hydroxides.
Of the rocks which contain sulphide ore, mostly limestone and quartzite rocks show a certain solubility in the water. Their reaction products do therefore enter into the mine water.

The water which is forced out from the mine can contain a certain amount of mud, approximately of the composition of the ore; metal ions, hydrogen and hydroxyl ions, and sulphate, carbonate and silica ions of various proportions. Besides the water which penetrates into the mine, also the water used in the mining process is brought up. Water is used to combat dust and for hydraulic filling of excavated mine space. These waters cannot be separated from mine water, and in the mine both of these will get mixed.

Water which penetrates into the cracks of the bedrock is often very clean. Therefore, in many mines a fresh water supply has been established, from which a first class water is obtained.

On a chemical dissolution or disintegration of sulphide minerals like copper-pyrite and sulphurpyrite, even certain micro-organisms do have an influence. They belong to the Thiobacillus family. When hydrogen is released, these transform sulphur from sulfide into sulphate, and two-value iron into three-value iron. This accelerates the disintegration and acts as a kind of catalyst for the reactions. These bacteria are active only at a pH-value of less than 3.5. Families of this type have been cultivated in cultures taken in Boliden and Kristinebergs Mines, which environment is favourable for them. In most sulphide ore mines of Sweden, they have minor significance. They have more possibility to be developed in the mountains above the earth, if these are exposed to air and water. Chemical soaking of sulphide ore of low value, with the help of bacteria, has been one important
method to extract copper in acid areas.

Depending on the content of alien substances, the pumped out mine water can be classified into three categories: waters of low, moderate and high metal content. Water with low metal content is neutral or slightly alkaline. Copper, zinc and lead content is under 0.1, 1.0 resp. 0.3 ppm. Water with moderate metal content is neutral: these contents are below 1.0, 10 resp. 2 ppm.

In water with strong metal content the pH-value is approximately 3. Metal content can exceed the latter type by 10 to 100 fold.
Most pumped up mine water nowadays belongs to the first or second category. Mine water with strong metal content occurred in its time in the Boliden Mine but is found now only in the Kristineberg Mine.

Mine water with slight metal content is disposed of into water courses after purification in the mine settling pools. Often the water is disposed of via a dike or enclosed area, through which further self-purification is obtained. Mine water with a moderate metal content undergoes a similar purification process.

When the water can be led out together with treatment water, this approach is always chosen because it enables good purification. Mine water with a high metal content is always purified before disposal. Methods for long range purification of mine water are under development.

![Fig. 3 Flotation principle](image)

As I mentioned in the introduction, the extracted ore is handled
by treatment, whereby the sulfide minerals are separated from each other and from mineral-less ore material. In order to reduce the transportation cost of mineral-less material which forms most of the ore and to make the mining worthwhile, the treatment plants must be established nearby the mine. Sulfide ore treatment is based on a flotation process. The ore is crushed; thereafter it is ground into fine-grained material in water. Thus, the various minerals are separated. The sulfide mineral is selectively/hydrophobic with so-called collector-reagent and is brought into contact with airstreams. The airstreams extract or float the sulfide minerals in the foam concentrate. After treatment, the material from which the minerals have been removed will remain as a residue in the water phase. The mixture is called treatment water. Its composition depends on the ore treated and the flotation medium used in the process.

Mineralogically speaking, the residue, or so-called treatment-sand, consists of rock minerals and smaller amounts of sulfide minerals which were lost in flotation. The sand is mostly sterile. The amount of sand depends on the ore content. In an ore with a low content, it can constitute over 97% of the weight of the ore; in more complex ores it often constitutes half of the weight.

In flotation, 1.5 to 5 m$^3$ of water is used per (metric) ton of ore. The lower figure refers to simple ores, the higher figure for complex ores. Flotation requires the water used to be very pure. During flotation, the surface forces of the newly-formed mineral are utilized. Oils, tensides* and residues of sanitary water make a selective flotation in a pure concentrate impossible. For this reason, treatment plants are located near mines, where a reasonably clean water supply is available, usually from flowing streams or lakes. In order to ensure a steady supply, some damming is occasionally

* (A substance increasing surface tension? – Trans.)
necessary.

Flotation now occurs in an alkaline environment. During the process of grinding the ore, and flotation, soda or lime is added. The pH-value of the pulp is usually approximately 8 for simple ores and over 9 for complex ores. Therefore, there is no metal dissolution during flotation, although, sometimes smaller amounts of such metal salts as copper sulphate or zinc sulphate are added. Metal ions settle selectively on the surface of sulfide minerals, and are used to control flotation and float the mineral in question.

The flotation medium contains a collector and a foamer. The former is usually composed of xanthate, the latter of terpineol. These substances are absorbed on the surface of the sulfide ores and up to 95% is removed in a sulfide mineral skim. The remainder is reduced to pulp.

The treatment sand has a sulfide ore low content and the metal content is in insoluble form. With suitable deposits this metal content can be neutralized for a long time.

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![Diagram](image)

**Fig. 4** Flotation treatment of a complex sulfide ore
The water phase usually has a pH-value between 7.5 and 10. Its Cu, Zn and Pb contents are less than 0.05, 0.1, and 0.1 ppm respectively. The amount of organic matter reaches approx. 1 ppm. The water is hard because of the addition of alkalis. Its sulphate content may reach approximately 300 ppm.

The development of treatment processes during the last decade has been directed at flotation in alkaline pulp, among others, for environmental reasons. Previously, flotation was frequently at pH-values below 7, achieved by adding sulphuric acid. Thanks to comprehensive research alkaline flotation has been performed as successfully as the acid process. The shift to flotation in an alkaline medium has also led to the possibility of handling pit water effectively. Treatment water has significant neutralizing capacity. Through the mixing of pit water and treatment water, the former can be neutralized, separating the metal ions as metal hydroxides. In the presence of treatment sand, adsorption of metal hydroxides occurs on the rock particles. When the treatment water is cleaned of sand afterwards through sedimentation, the effective purification of the pit water also occurs.

This method has been used successfully at treatment-plants in Boliden and Kristineberg, and has proven to be useful for pit water at other locations too. Pit water has a sterilizing effect on sanitized sewage because it contains metal ions. This effect has been utilized so that the pit water is mixed with sanitized sewage, with the addition of treatment water. Sedimentation of sand and organic mud occurs simultaneously, and clean water with a low concentration of organic matter is obtained.

In order to reduce the future use of natural water and reduce wastage of the water used, attempts are being made to recycle water in the treatment process. Within the process, approximately 30% of the water required is recovered. Treatment water, which is relatively hard because of the
addition of alkalis and which is mixed with pit water, has until now been reused relatively sparingly in the flotation process. In simpler flotations it has been shown that by circulating the treatment water from the hopper, it is possible to meet approximately half of the water required. Even in the treatment of complex ores in certain flotation phases, recovered water has been used successfully. Trend of development is towards increased circulation and reduced waste of the water used.

**Handling of treatment water**

Treatment water sediments from sulfide ores contain between 50 and 98% of its solid matter in the form of treatment sand. The removal of sand sediment deposits and the purification of water constitute from the environmental standpoint, one of the most important questions in mind. Since this question will be treated in a special lecture at the spring meeting, only few comments are made here.

The usual practice is to arrange for a common sedimentation and purification hopper for treatment water. The volume is such that the sand yield expected from the ore can be accommodated, and the surface is adequate for purification. For these reasons, the required surface is large and can be obtained only in low-lying areas. This consideration often requires the damming of lakes or other bodies of water. Though ecological considerations are often raised with regard to this procedure, it appears to be most suitable in our climate. The alternative is to build storage facilities on land. This system, which has been used in South Africa, causes among other things large damming and other erosion problems which cannot be controlled. Together
with the sand from sulfide ore treatment, the material is exposed to disintegration which may make control of solutions of metallic salts difficult.

When treatment sand is stored, disintegration is retarded when it is mostly covered with water. Therefore, the placement of sand in dammed up low areas is preferable, and has been a common practice in our country. By carrying the treatment water into settlement or purification tanks, with few exceptions, very fast sedimentation and good purification is achieved due to the water's alkaline content. Where purification is not adequate, it can be improved through addition of lime to treatment water. Such water from purification storage tanks also shows acceptable concentration, with few exceptions, considering that water's sift-depth is at least 1 m deep and that copper, zinc and lead contents are - 0.05, 0.5 and 0.1 ppm, respectively.

In order to reduce the effect of transporting the water and achieve more effective purification of mine and treatment water, central treatment plants have proven to be suitable. Their location has been selected on the basis of various features: the distance to the mine, supply of natural water and utilization of less valuable areas, from an environmental viewpoint, for the storage of sand and the purification of water; and access of water to recipients where the remaining matter can be spread out quickly and finally destroyed.

When excavating the mines, increasing amounts of fill material are utilized to stabilize the excavated space in the rock. The coarser part of the treatment sand has proven to be very suitable for this purpose. Therefore, the central treatment plant is provided with equipment to separate coarse sand. This is transported to mines and for use there.
Up to fifty percent of the sand can be utilized in this manner, while extending the time that the sand-storage space can be used.

Fig. 5 Schematic illustration of processing of mine water and treatment water

**Mine operation and water hygiene**

Are the questions of sulfide mine ore water resolved from an environmental viewpoint? It would be audacious to answer this question with a simple yes or no in front of this audience for many reasons. The purpose of this lecture has not been to attempt to answer this question but to describe the problem which exists and the causes of which are now clear. One may say that the description I have tried to give has been one-sided and does not give a general view of the environmental question as such. Generally, the environmental question is not lost as long as the physical environment is considered, and as long as foreign matter is removed in connection with mine operations. With this definition of the problem, one is still far from a solution.

For decades the mining industry has worked very actively in order
to obtain better and better solutions of its water problems, and has generally succeeded. The solutions which are reached today should be looked at in relation to established concepts in planning of mining operations. The main aim has been to organize activities in such a manner that the water, which is withdrawn and its effects, can be tolerated.

As demand increases, so does the responsibility of mining managers in the handling of "housekeeping" as regards water. As miners they are aware of it and they are engaged in broad-ranging research and development in the area of water and other problems in the mining industry.

Summary

This paper deals with the two types of water which occur in sulfide ore mines, pit water and treatment water, which are the most important in this context. The origin of this water, with respect to composition, properties, treatment, removal and significance for the environment has been covered.

The mine water's composition is determined by ground water's effect on the ore. After purification in pools, the water is pumped out to the surface. Depending on the composition further purification may be performed.

Treatment water is composed of rock substances, in the form of mud in the water which remain after the sulfide minerals have been extracted by the flotation process.

Effective sedimentation and purification is achieved through simultaneous treatment of pit and treatment water.

The problems of sulfide ore pit water have been and continue to be a subject of research and study testing.